CHILD RESTRAINT SYSTEM ASSESSMENT PROGRAM IN JAPAN

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ABSTRACT

This paper attempts to summarize Japan's child restraint system (CRS) assessment program, which was initiated in 2001. The CRS assessment program was launched to assess the performance of universal CRSs in response to the rising numbers of killed or injured child car passengers in recent years as well as in response to the introduction of a regulation in April 2000 what mandates the use of CRSs for children under six years old.

The assessment comprised frontal collision and usability tests (evaluation of ease of use). The frontal collision tests were carried out using the body of a production car, which was mounted on a sled. The test speed was 55 km/h, the same as used in Japan's New Car Assessment Program (JNCAP). The usability test assessed the design and foolproof features of the CRSs.

The assessment covered CRSs for infants (up to 10 kg) and toddlers (9 kg to 18 kg). The CRSs for infants were examined for backward-facing and/or bed. All toddler CRSs tested were forward-facing.

The evaluation items for the frontal collision tests were decided in reference to Japanese, United States and European safety standards.

Since it is important to check whether weaker parts of toddlers are at risk of injury by pressure from restraints such as harnesses, padding, we considered adopting electric pressure sensors to measure abdominal pressure.

1. INTRODUCTION

In April 2000, the National Police Agency mandated the use of CRSs due to the increasing number of accidents involving child passengers. Since then, the use rate of CRSs has risen with the provision of a public information campaign.

Numerous types and designs of CRSs, including imported products, are available to consumers. However, there was at the time, limited information available to consumers in terms of safety and usability.

Therefore, the Ministry of Land, Infrastructure and Transport (MLIT) and the National Organization for Automotive Safety & Victims' Aid (OSA) in cooperation conducted a CRS assessment program to evaluate the safety and usability of the CRSs sold domestically. The objectives of this program are to encourage users' safety minds, to promote the spread of safer CRSs through the selection of the users, and to encourage CRS manufactures to undertake more research and development effort in producing safer CRSs (Figure 1).

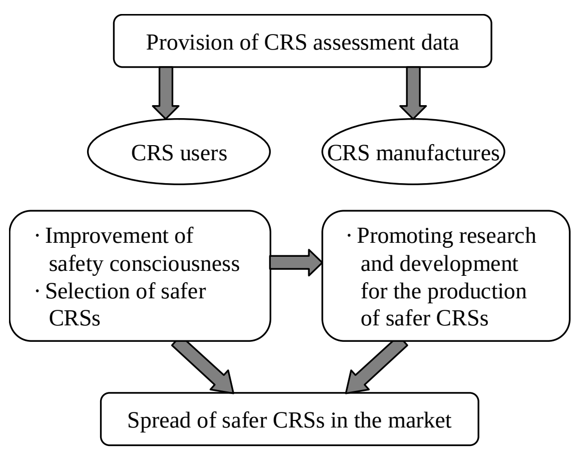


Figure 1 Objectives of CRS assessment

2. REAL WORLD ACCIDENTS

Figure 2 illustrates the yearly trend of the number of killed or injured children in the National Police Agency's nationwide statistics for traffic accidents. It indicates that a disproportionately high and growing number of child passengers have been killed or injured.

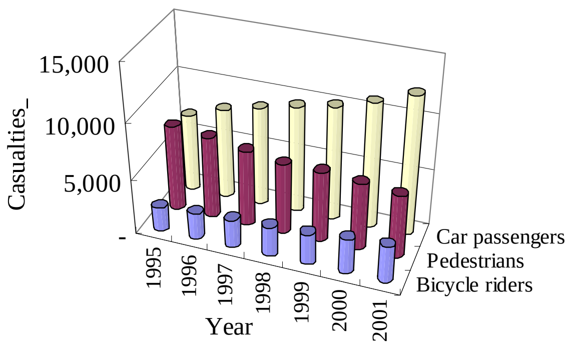


Figure 2 Yearly casualties of children under 6 years (Reference [1])

Table 1 presents the distribution of collision types using the data of the Institute for Traffic Accident Research and Data Analysis (ITARDA). According to the statistics, almost half of the total collisions is frontal collision. This pattern is the same for accidents that involve child occupants.

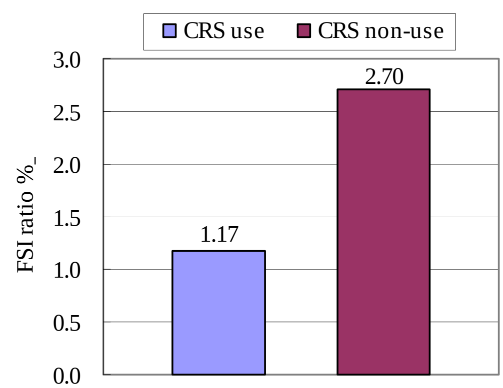
Table 1 Distribution of collision types (Reference [1], 1993-1998)

Collision types	Involved children under 6 years		All accidents	
	Number of accidents	Rate %	Number of accidents	Rate %
Front	30	47	959	54
Side	20	31	379	21
Rear	5	8	141	8
Others	9	14	303	17

Child injury data were divided into data of children who used CRSs and data of those who did not. Figure 3 compares their FSI ratio. The FSI ratio of children who used CRSs is 1.17%; that of children who did not use CRSs is 2.70%. The FSI ratio of the children who used CRSs is lower than that of the children who did not use CRSs. Consequently, CRSs reduce child injuries.

Figure 4 shows the results of the investigations for CRS installation realities conducted by the Japan Automobile Federation (JAF). The rate of the CRSs installed tightly is merely 29.1 %. Namely, it can be thought that most of CRSs are used in the incomplete state.

Injury data of 554 children were divided into data of those who used CRSs correctly and data of those who used CRSs incompletely. Figure 5 describes the results of the analysis relating to use condition of CRSs by each child's ejection mode. Thirty-one children were ejected from CRSs or the vehicles due to accidents, thirty of the thirty-one ejected children used CRSs incompletely. Incompletely used CRSs thus cannot achieve their designed restraint performance.



$$\text{FSI ratio} = \frac{\text{Fatalities + Serious injuries}}{\text{Total number of casualties}}$$

Figure 3 FSI ratios of children with and without CRSs (Reference [2], 1996-2000)

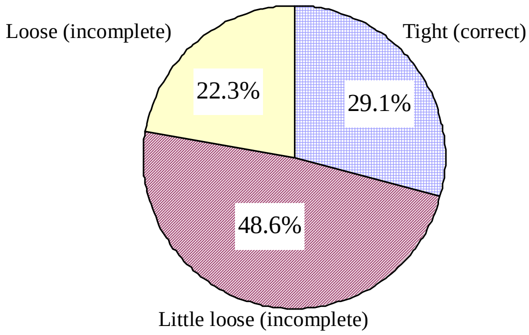


Figure 4 Actual conditions of the installation of forward-facing toddler CRSs (Reference [3], 2002)

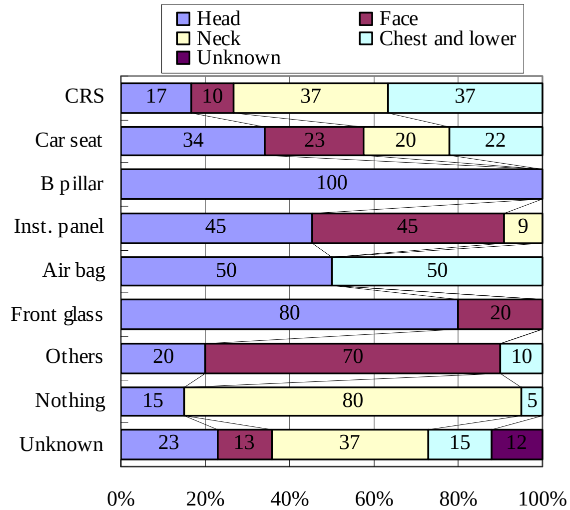


Figure 6 Injured regions of child body and cause of injuries (Reference [2], 2000)

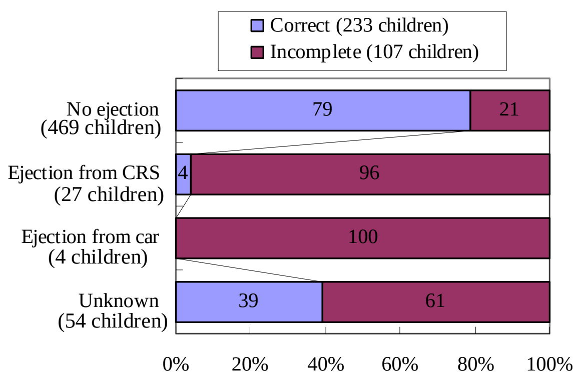


Figure 5 Child ejection and correct/incomplete use of CRS (Reference [2], 2000)

Figure 6 shows analysis results of child injury locations by each object that injured them. Injuries to the head represent 17% of all injuries caused by CRSs. The rates of injuries by objects other than CRSs are 34 to 100%. These rates are higher than that of the injuries by CRSs themselves, since incomplete use of CRSs causes the child to collide with car interior parts.

Consequently, it can be concluded that it is absolutely important to execute the usability evaluation test.

Figures 7 and 8 depict the distribution of equivalent barrier speed. When test speed ΔV in the test is assumed to be equal to the equivalent threshold speed, a test speed of 55 km/h accounts for 97% of all ITARDA data. Comparing the distribution of equivalent barrier speed of accidents involving all data and children, the distribution of the equivalent barrier speed of accidents involving child occupants is obviously lower. The test speed of 55 km/h accounts for 99% of accidents involving child occupants.

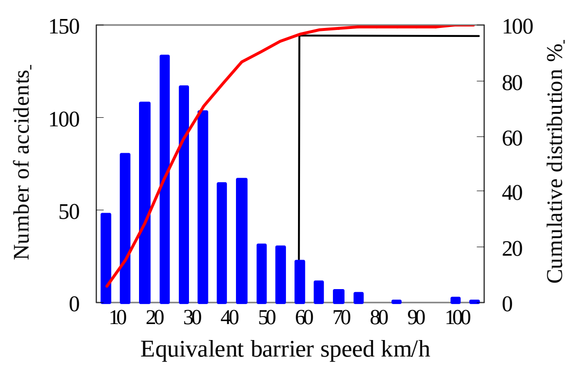


Figure 7 Distribution of equivalent barrier speed in all accidents (Reference [1], 1993-1999)

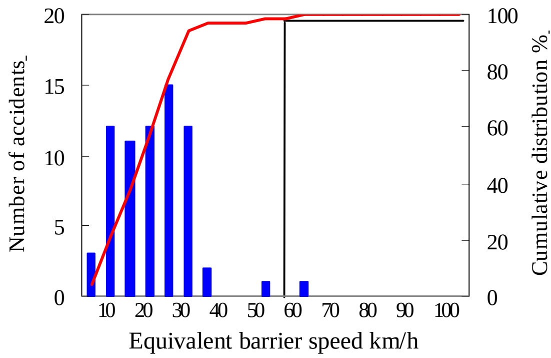


Figure 8 Distribution of equivalent barrier speed in accidents involving children under 6 years (Reference [1], 1993-1999)

3. TEST METHOD

Frontal crash tests were conducted as a safety performance evaluation test based on accident data. An expert installed and fitted CRS for these tests. A usability evaluation is important to guarantee safe performance. Therefore, we performed a usability evaluation test in addition to the frontal collision test.

The CRSs tested were for infants weighing less than 10 kg and for toddlers weighing from 9 to 18 kg. Because most CRSs used domestically are universal types that are fitted in most or all car models, only universal types were targeted in these tests. CRSs for infants were tested with the occupant facing the rear. Bed-type models were also tested in that position, and CRSs for toddlers were tested with the occupant facing forward. The examined CRSs were selected in order from the best-selling model down. However, CRSs models soon to be withdrawn from the market were not tested.

3.1 Frontal Collision Test

(1) Test configuration

The test type adopted was frontal collision, since this type of accident is the most common. The body of a production car was attached to the sled test device as shown in Figure 9. The CRSs were fixed behind the driver's seat (right-hand seat in the second row).

The test speed was 55 km/h, the same as in the full-frontal crash tests used by the JNCAP.

(2) Cut body

A Toyota Estima (manufactured in 2000, eight-passenger design) was used for the car body (Figure 10). This is a people-carrier model, a type often used by families and popular in Japan. Furthermore, it is compatible with a wide range of CRSs, another reason that this model was selected. The order of superiority or inferiority of CRSs changed very little, even when the type of the car body was changed. We therefore decided to test the CRSs using only one car model. If the CRS interfered with the headrest of the vehicle seat, the headrest was detached. The seats of this model were equipped with a three-point seatbelt with a CRS anchoring function (Automatic Locking Retractor function). The CRS was fixed using this seatbelt in the test. The vehicle seat and the seatbelt used to fix the CRS were replaced with new parts before each test.

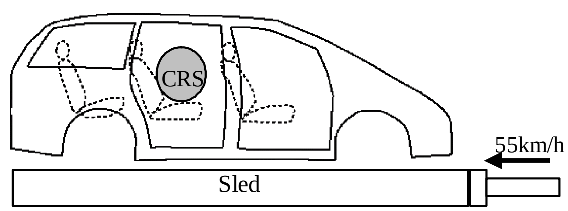


Figure 9 Test configuration

Figure 10 Cut body (Toyota Estima)

(3) Sled acceleration

The sled acceleration curve was adjusted to satisfy the corridor provided in ECE R.44 [4]. In addition, a representative acceleration curve was established to secure test reproducibility (Figure 11). The sled acceleration curve was set to follow this curve as closely as possible.

(4) Dummies

The maximum sized dummies within the range of each category of CRSs were used (Figure 12). The biggest available dummies were used to maximize the restraint force needed by the CRSs and to subject each CRS to the worst-case scenario.

The TNO P3/4 dummy was used in the tests on the rearward-facing infant CRSs. This is the only dummy for a nine-month-old available. The TNO P3/4 is used for certification tests in Japan, Europe, and the United States. The CRABI 6MO dummy was used for the bed-type CRS tests. The CRABI 6MO dummy is the latest six-month-old child dummy, and is believed to have the highest biofidelity. The Hybrid-III 3YO dummy was used for the tests on the forward-facing toddler CRSs. This dummy is the newest version, and is used for certification testing in the United States.

(5) Measurement items

The acceleration of the sled and the measurement items in the dummy were electronically measured (Table 2). The measurement items in the dummy varied depending on the kind of dummy (and CRS category). Items for reference in future evaluations, as well as measurement items for immediate evaluation, were measured.

Optical measurement items varied depending on the type of dummy in the same way as the electrical measurement items (Table 3). A high-speed video movie was used to analyze the dummy movement and observe the state of restraint. Both cameras fixed to the sled and ground-based cameras were used. The frame speed was 500 fps or more.

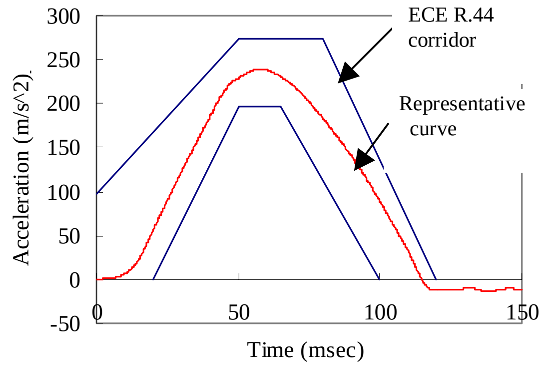
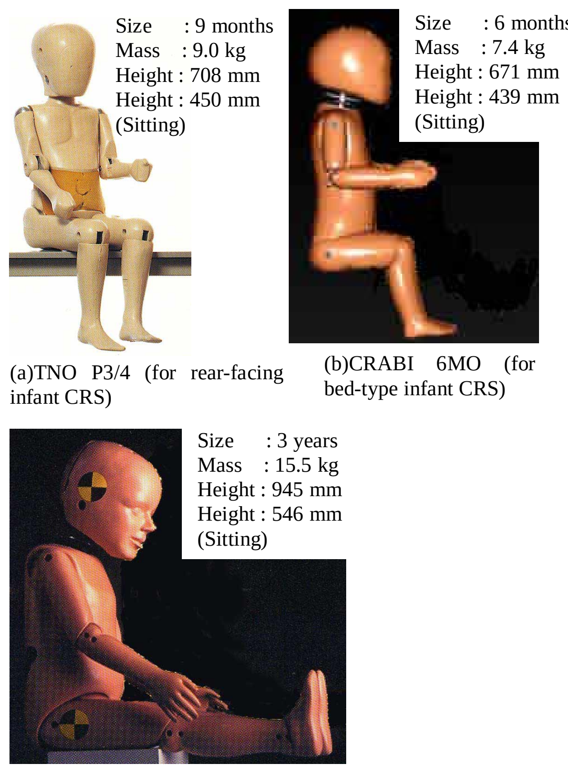


Figure 11 Sled acceleration curve



(a)TNO P3/4 (for rear-facing infant CRS)

(b)CRABI 6MO (for bed-type infant CRS)

(c)Hybrid-III 3YO (for forward-facing toddler CRS)

Figure 12 Child dummies for CRS assessment

Table 2 Electrical measurement items

Regions	Rear-facing infant CRS	Bed-type infant CRS	Forward-facing toddler CRS
Head acceleration	X, Y, Z	X, Y, Z	X, Y, Z
Neck load	X, Z	X, Y, Z	X, Y, Z
Neck moment	Y	X, Y, Z	X, Y, Z
Chest acceleration	X, Y, Z	X, Y, Z	X, Y, Z
Chest deflection			X
Sled acceleration	X	X	X

Table 3 Optical measurement items

Rear-facing infant CRS	Bed-type infant CRS	Forward-facing toddler CRS
- Inclination angle of seat back - Projection of the head from CRS	- Head excursion in forward direction - Bottom angle of bed - Projection of the head from CRS	- Head excursion in forward direction - Knee excursion in forward direction

(6) Reclining angle of CRS

The CRS reclining angle was adjusted using their reclining mechanism. Rearward-facing infant CRSs were adjusted to the maximum reclining angle for each model; forward-facing toddler CRSs were adjusted to the most upright reclining angle.

(7) Setting of CRS and dummy

Basically, the CRS and the dummy were installed according to ECE R.44, since domestic certification tests use a similar installation method.

3.2 Usability Evaluation Test

The usability evaluation test employed the same Estima car body as for the frontal collision test. Five neutral experts acted as evaluators. Five evaluators were employed to ensure objectivity of the evaluation results.

4. EVALUATION METHOD

This program evaluated both the frontal collision test result and the usability evaluation test result because it is extremely difficult to combine safety performance and usability.

4.1 Frontal Collision Test

The evaluation items and the criteria for the frontal collision test result were established for each of the three CRS categories rearward-facing infant CRSs, bed-type infant CRSs, and forward-facing toddler CRSs; (see Tables 4, 5, and 6).

There is a risk of injury to weaker parts of the body by restraining parts such as the harness and pads of the forward-facing toddler CRSs. We decided to evaluate injuries caused by the restraint system for the forward-facing toddler CRSs. The restraint of the dummy during the collision test was observed using a high-speed video movie. The static state of the restraint was also confirmed. The results were considered "×" ("×" indicates "failure") if the restraint system pressed against the weak parts of the body such as the neck, abdomen or crotch or if the restraint moved from its proper position. When the extent of injury caused by the restraint was negligible, however, this was noted.

The dropping of the dummy from the vehicle seat was also evaluated.

The damage from fixture parts is judged by touching with the hand and observation. Energy-absorbing mechanisms made public beforehand were excluded from the evaluation of damage. Results were judged as "◎" ("◎" indicates "satisfactory") if there were no crack, exfoliation, deformation, loosening of threads, or buttons coming off and if the strength maintenance function of the CRS or the vehicle seatbelt was not impaired. When multiple collisions are assumed, damage that would result in injury in a secondary collision was considered as "×". "×" was also assigned when there is damage that might directly injure the child. The results were rated as "○" ("○" indicates "acceptable") if the damage was slight.

Overall evaluations of "Excellent", "Good", "Normal", or "Not recommended" were made based on the evaluation results for each item (Table 7). For instance, the overall evaluation is excellent when all items are "◎". The overall evaluation is "Not recommended" when one or more items are rated as "×". CRSs designed for use by both infants and toddlers were assigned overall evaluations for infants and toddlers in parallel.

Table 4 Individual rating for rear-facing infant CRS

Rating items	Criteria	Rating
Damage of such as fixtures	No	◎
	Slight	○
	Terrible	×
Inclination angle of seat back **(A)**	60deg. ≥ angle	◎
	60deg. < angle ≤ 70deg.	○
	70deg. < angle	×
Projection of the head from CRS **(B)**	No projection	◎
	73mm ≥ projection	○
	73mm < projection	×
Chest resultant 3ms acceleration **(C)**	539m/s^2(55G) ≥ acc.	◎
	539m/s^2(55G) < acc.	○
Release of buckle		×
Released from seatbelt		×

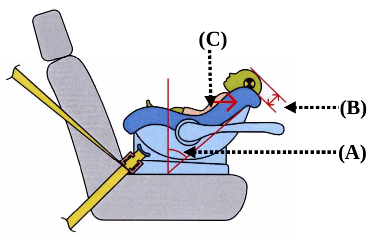


Table 5 Individual rating for bed-type infant CRS

Rating items	Criteria	Rating
Damage of such as fixtures	No	◎
	Slight	○
	Terrible	×
Restraining condition (Projection of the head from CRS, bottom angle of bed **(A)**)	Rotating rearward (No projection of the head)	◎
	No rotation (No projection of the head)	○
	Rotating forward or projection of the head	×
Head excursion in forward direction **(B)**	600mm ≥ excursion	◎
	600mm < excursion ≤ 750mm	○
	750mm < excursion	×
Chest resultant 3ms acceleration **(C)**	539m/s^2(55G) ≥ acc.	◎
	539m/s^2(55G) < acc.	○
Release of buckle		×
Released from seatbelt		×

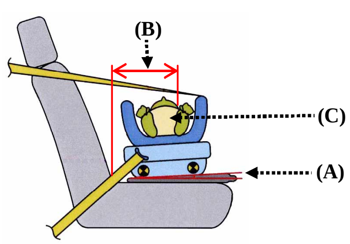


Table 6 Individual rating for forward-facing toddler CRS

Rating items	Criteria	Rating
Damages of such as fixtures	No	◎
	Slight	○
	Terrible	×
Head excursion in forward direction **(A)**	550mm ≥ excursion	◎
	550mm < excursion ≤ 700mm	○
	700mm < excursion	×
Head resultant 3ms acceleration **(B)**	785m/s^2(80G) ≥ acc.	◎
	785m/s^2(80G) < acc.	○
Chest resultant 3ms acceleration **(C)**	588m/s^2(60G) ≥ acc.	◎
	588m/s^2(60G) < acc.	○
Release of buckle		×
Released from seatbelt		×
Possibility of injury, such as that a harness press weak parts of the child's body (abdomen etc.).		×
Dropped from vehicle seat		×

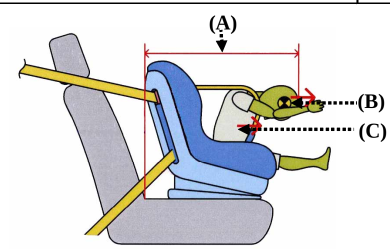


Table 7 Overall evaluations for frontal collision test

Excellent	No "× " and the results of all 4 rating items are "◎ ".
Good	No "× ", the results of any 3 rating items are "◎ "and the result of the rest of rating item is "○ ".
Normal	No "× " and the number of "◎ " is two or less.
Not recommended	If there is any "× " as the result of the test.

4.2 Usability Evaluation Test

Each evaluator evaluated the usability of CRSs according to an evaluation sheet (Table 8).
An individual item is evaluated on a five-point scale ranging from 1 to 5. The standard point of these evaluations is 3 points. If the evaluators judged different evaluation results, they have to consult together. An evaluation item that does not correspond to an individual item was treated as invalid. The average points for each area "Instruction manual, etc.", "Information on CRS", "Structural design", "Ease of installation", and "Ease of fitting" were calculated. These average points were displayed using a radar chart (Figure 13).

Table 8 Evaluation items and standard levels of usability evaluation test

Area	Target	Standard performance level
Instruction manual, etc.	Instruction manual	Provides instructions on installation and fitting of CRS. Contains references mandated by technical standards.
		Method of installation and fitting can be understood by the written and visual instructions provided.
		Contains a warning about installation of the CRS in the front passenger's seat. Contains clear references mandated by relevant technical standards.
		Contains explanations of appropriate method of installing and fitting CRS according to child's body size.
		Contains explanation of how to confirm that the CRS is properly installed.
	Package	Weight or height of children for which the CRS is appropriate is indicated on the package (in Japanese). References mandated by technical standards, standards with which the CRS is compliant are clearly indicated.
Information on CRS	Information content	Indicates method of installation.
		Includes a warning about installation of the CRS in the front passenger's seat. Includes all warnings and cautionary references mandated by relevant technical standards.
		Expressions are appropriate, not likely to lead to misunderstandings.
		Provides contact details for further information on the product.
		Standards with which the CRS is compliant are clearly indicated (visual representations also acceptable).
	Belt guide	Indications are in written form.
Structural design	Movable structures (usability of reclining, rotation structures)	Are certain to lock. Location of lever switch is easy to understand.
	Seat cover (ease of maintenance)	Proper attachment method for harness is not difficult to understand when replacing the seat cover after it has been removed. Seat cover is not difficult to re-attach.
	Internal storage (for instruction manual, accessories)	Product offers internal space to store instruction manual, accessories (if provided).
Ease of installation (installation to vehicle seat)	Belt routing	Miss-attachment is unlikely, belt easily passes through. Twisting or folding of vehicle's seatbelt does not occur.
	Installation	CRS can easily be secured in place by one person (need to put weight on product while installing is acceptable).
		Metal fasteners, etc. are easy to use and allow for well-secured installation.
		Forward direction: CRS is not unsteady after installation (when top of product is pulled with a force of 98N, displacement is 30mm or more, but less than 50mm). Backward direction: Seatback is at an angle of 45 degrees ± less than 10 degrees (placement of material between CRS and vehicle seat is acceptable).
Ease of fitting	Harness	Location of slots is easy to understand.
		No difficulty is encountered in adjustment.
	Buckle	Can easily be securely locked.
		Force required to release buckle is sufficient to make it difficult for child to release locking mechanism (greater than 40N).
	Fitting	A specialist can seat the dummy in an appropriate position in less than 1 minute.

Each survey area is scored on a scale of 1 to 5, with a standard score of 3.

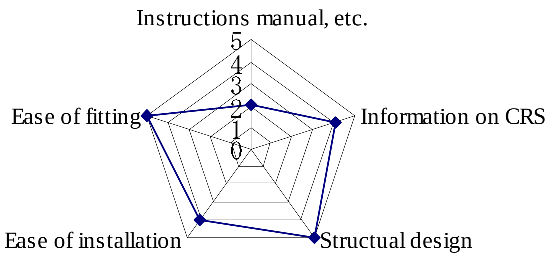


Figure 13 Displaying of usability evaluation test results (Example)

5. EVALUATION RESULTS OF CRS ASSESSMENT PROGRAM

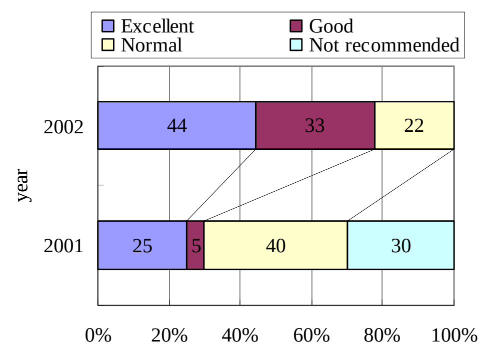
Twenty-one rearward-facing infant CRSs and twenty forward-facing toddler CRSs were evaluated in the CRS assessment program in 2001. Nine rearward-facing infant CRSs, a bed-type infant CRS and nine forward-facing toddler CRSs were evaluated CRSs in 2002.

Figure 14 presents the yearly distribution of the evaluation results in the frontal collision tests. Comparing the distribution of the evaluation results each year, the distribution of the evaluation results in 2002 is obviously better. Actually, in the products for infants, six were "Not recommended" in 2001, none was "Not recommended" in 2002. Likewise, in the products for toddlers, eight were "Not recommended" in 2001, none was "Not recommended" in 2002.

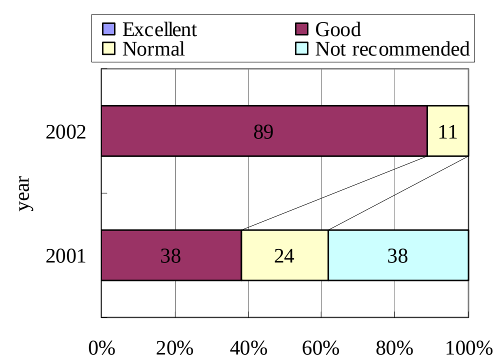
Table 9 shows the evaluation results of infant CRSs by each rating item in the frontal collision tests. Six infant CRSs that evaluated as "Not recommended" in 2001 were rated as "×" in the rating item of seat back angle. There is no product rated as "×" in rating items in 2002. The increase in the ratio of products that rated as "◎" in the item of damage of fixtures is remarkable. Table 10 shows the evaluation results of toddler CRSs by each rating item. The breakdowns of eight toddler CRSs evaluated as "Not recommended" in 2001 are three products that rated as "×" in the item of damage of fixtures, four products that rated as "×" in the item of head excursion and one product that rated as "×" in the items both of damage and head excursion. There is no product rated as "×" in rating items in 2002. The increase in the ratio of products that rated as "◎" in the item of damage is remarkable, as well as the trend of infant CRSs.

Table 11 shows the yearly average points of each evaluation area in the usability evaluation test. All average points in 2002 were higher than those in 2001.

New domestic safety standard for CRSs has been enforced in April 2000. It is more stringent standard than the previous one. The enforcement of new standard to CRSs which were produced by the end of 2002 was exempted. Accordingly, two categories of the products which suited the new standard and only the old standard were included in the selection of the CRS assessment in 2001. On the other hand, all assessed CRSs in 2002 suited new standard. Consequently, the evaluation results in 2002 were better than those in 2001.



(a) Rear-facing infant CRSs



(b) Forward-facing toddler CRSs

Figure 14 Overall evaluation results of frontal collision test

Table 9 Evaluation results of infant CRSs by rating item in frontal collision test

Rating items	2001			2002		
	◎	○	×	◎	○	×
Damage of fixtures	6	14	0	8	1	0
Seat back angle	10	4	6	7	2	0
Head projection	15	5	0	8	1	0
Chest acceleration	12	8		6	3	
Others			0			0

Table 10 Evaluation results of toddler CRSs by rating item in frontal collision test

Rating items	2001			2002		
	◎	○	×	◎	○	×
Damage of fixtures	12	12	4	8	1	0
Head excursion	0	22	5	1	8	0
Head acceleration	26	2		8	1	
Chest acceleration	28	0		9	0	
Others			0			0

Table 11 Evaluation results of usability evaluation test

Evaluation area	Average points	
	2001	2002
Instruction manual, etc.	3.1	3.5
Information on CRS	3.4	3.5
Structural design	2.8	3.6
Ease of installation	3.2	4.0
Ease of fitting	3.0	3.6

6. PUBLICATION OF EVALUATION

The evaluation results of frontal collision tests and usability evaluation tests are being published as booklets and being distributed free of charge. The evaluation is also published on the websites of MLIT (http://www.mlit.go.jp) and OSA (http://www.osa. go.jp).

After the evaluation results were made public, the users came to buy the products which obtained better evaluation in the CRS assessment program. At the same time, the CRS manufactures came to develop safer products which were considered the evaluation of the CRS assessment program. Consequently, we believe that this program acted as a major contributor to improving of CRS safety.

7. STUDY FOR QUANTITATIVE EVALUATION OF ABDOMINAL INJURY

Injury by the restraint could not be evaluated for vest-type CRSs using the previous method of arriving at a judgment. The level of pressure that the harness exerts on the abdomen could not be estimated using the high-speed video movie. The condition of the restraint and the behavior of the dummy during the test were complex. To measure the pressure on the dummy abdomen and to evaluate injury by abdominal pressure, we launched another study. The measurement method and the evaluation method were examined using an electronic pressure sensor as follows.

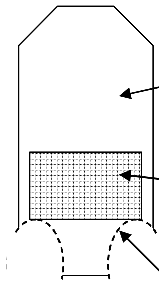
7.1 Specifications of Electrical Pressure Measurement System

An electrical pressure measurement system satisfying the following specifications was used.

- The range of the measurement should be 0 to 1.96MPa
- The analog-digital converter should have 8-bit or better resolution.
- The measurement area should be 250mm vertically and 120mm horizontally.
- The interval of measurement parts should be 10mm vertically and horizontally.
- The sampling rate should be 500Hz or more.

7.2 Setting Position for Electrical Pressure Sensor

The sensor was set on the abdomen of a Hybrid-III 3YO, so that the lower edge of the sensor might become the upper position of the hollows for installation of the legs (Figure 15). The area of the measurement was larger than the abdomen (Figure 16).



(a)Installation position

(b)Actual situation

Figure 15 Setting position for electronic pressure sensor

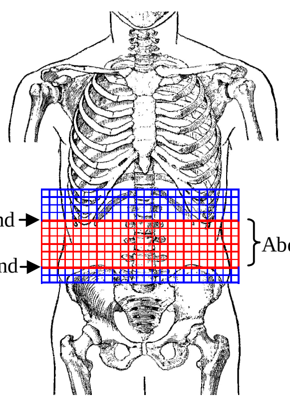


Figure 16 Image of measurement area

8. CONCLUSION

(1) A CRS assessment program was implemented in Japan in 2001.
(2) To reproduce actual usage of CRSs, we adopted the car body for the frontal collision test and the usability evaluation test.
(3) In the safety performance evaluation test, frontal collision was adopted, since this kind of accident is the most common.
(4) In the usability evaluation test, a quasi-quantitative grading method was adopted in which five experts judged the results.
(5) After the evaluation results were made public, the users tend to buy the products which obtained better evaluation in the CRS assessment program. At the same time, the CRS manufactures tend to develop safer products which were considered the evaluation of the CRS assessment program. Consequently, we recognize that this program contributed significantly to safety improvements of CRSs.

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